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Damping Loss Factor Determination of Glass and Graphite Epoxy Laminated Composites Using Vertically Oriented Cantilever Beams

by

Roger M. Crane

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DTRC-SME-89/62 Damping Loss Factor Determination of Glass and Graphite Epoxy Laminated Composites Using Vertically Oriented Cantilever Beams

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Material damping of laminated composites is experimentally determined using a cantilever beam test with an impulse excitation. The beam is oriented vertically as opposed to the traditional horizontal orientation. Data acquisition and manipulation is carried out using an IBM PC-AT with a high speed A/D board and analysis software. Unidirectional continuous fiber 0, 90 and +45 degree laminates were fabricated from glass/epoxy (Hercules S2-Glass/3501-6) and graphite/epoxy (Hercules AS4/3501-6) to investigate the effect of fiber and matrix properties as a function of frequency, up to 1000 Hz., on the damping of composites. The vertical orientation provided loss factor results that were significantly different than the tests conducted on the horizontally oriented beams. The results using

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the vertical orientation are assumed to be more representative of the material loss factor since both accelerations and stresses are more uniform. The glass fiber composite had a higher loss factor than the graphite composites. The loss factor for the 0 degree AS4/3501-6 increased linearly as a function of frequency, whereas the 0 degree S2-Glass/3501-6 had a significant nonlinear increase in loss factor above 700 Hz. The 90 degree material exhibited a higher damping loss factor than the 0 degree, increasing nonlinearly with increasing frequency. The 90 degree orientation had loss factors that were a factor of 2 or greater than the 0 degree orientation. The ±45 AS4/3501-6 had a loss factor that increased with frequency similar to the 0 degree configuration.

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ABSTRACT

Material damping of laminated composites is experimentally determined using a cantilever beam test with an impulse excitation. The beam is oriented vertically as opposed to the traditional horizontal orientation. Data acquisition and manipulation is carried out using an IBM PC-AT with a high speed A/D board and analysis software. Unidirectional continuous fiber 0, 90 and ±45 degree laminates were fabricated from glass/epoxy (Hercules S2-Glass/3501-6) and graphite/epoxy (Hercules AS4/3501-6) to investigate the effect of fiber and matrix properties as a function of frequency, up to 1000 Hz., on the damping of composites. The vertical orientation provided loss factor results that were significantly different than the tests conducted on the horizontally oriented beams. The results using the vertical orientation are assumed to be more representative of the material loss factor since both accelerations and stresses are more uniform. The glass fiber composite had a higher loss factor than the graphite composites. The loss factor for the 0 degree AS4/3501-6 increased linearly as a function of frequency, whereas the 0 degree S2-Glass/3501-6 had a significant nonlinear increase in loss factor above 700 Hz. The 90 degree material exhibited a higher damping loss factor than the 0 degree, increasing nonlinearly with increasing frequency. The 90 degree orientation had loss factors that were a factor of 2 or greater than the 0 degree orientation. The ±45 AS4/3501-6 had a loss factor that increased with frequency similar to the 0 degree configuration.

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INTRODUCTION

Organic matrix composites are being investigated to determine their vibration damping loss factor in the frequency range of 10

to 1000 Hz. This frequency range is of interest since it is representative of the vibrational spectrum experienced by numerous structural applications.

In recent investigations(1,2) the damping loss factor of glass and graphite/epoxy composite materials were tested in the cantilever beam configuration where the specimen was oriented in the traditional horizontal position. This is the orientation which is utilized extensively in the industry to determine the damping loss factor of composites.(3-7) In these investigations, the authors are attempting to determine the composite material damping. Care is taken to minimize frictional losses, losses due to clamping, aerodynamic losses and losses due to material anomalies so that the material damping can be determined.

Material damping can be defined as any material characteristic which allows for the conversion of mechanical energy into some other form of irrecoverable energy. In its most basic form, the material damping is defined as the ratio of the change in stored energy, ΔW, to the maximum stored energy, W, during one cycle. The damping that will be reported herein is the damping loss factor, η where

$$\eta = \frac{\Delta W}{2\pi W} \tag{1}$$

In conventional metallic systems, this energy dissipation occurs through the transformation of mechanical energy into heat. For composite materials, there are numerous sources of energy

dissipation such as the viscoelastic response of the material constituents, thermoelastic conversion of mechanical energy into heat, friction at the fiber matrix interface and damage initiation and growth.

The tests results reported in reference 1 and 2 were significantly different than what was anticipated. Normally, the loss factor for viscoelastic materials initially increases with frequency.(8) The loss factors determined in references 1 and 2, however, showed a decrease with increasing frequency for the 90 degree glass and graphite epoxy composites tested. It was thought that these results may be due to the beam configuration coupled with the materials mechanical properties. In order to excite the low frequency vibrational modes, beam lengths become large compared with thickness. For laminated beams with low axial stiffness, these long beams can deform under their own weight, resulting in an nonuniform stress state through the beam thickness. As the beam is set into vibration, the stresses experienced by the beam may remain tensile on the top of the beam and compressive on the bottom side, as opposed to an oscillation between tension and compression. This may effect the displacement of the beam since the mechanical properties the composites may not be equal in compression and tension.

In addition, with the horizontal orientation, when the beam is excited, it is subjected to a combined applied and gravitational force. As the beam is accelerated downward, the

beam displacement is governed by the summation of these forces. When the motion of the beam reverses, the gravitational forces are acting opposite to the restoring forces of the beam, resulting in a reduction in beam tip displacement, see figure 1. The subsequent oscillation reversal will have a reduced restoring force, resulting in a slightly reduced displacement in the opposite direction. Since the loss factor is determined by monitoring the beam tip displacement or acceleration of the beam, the apparent loss factor may be greater than that of the material alone.

When a beam is supported in a vertical position, the gravitational effects should be minimized. In addition, the material is subjected to a uniform stress state, i.e. tension or compression depending on the position of the beam relative to the clamp. As such, the vertical orientation should minimize external environmental losses, resulting in the determination of the material loss factor.

The purpose of this investigation is to compare the loss factor of glass and graphite/epoxy composites determined with the beams in the vertical position to the results obtained previously with the beams oriented in the horizontal position. The specimens used in this investigation were machined from the same plates from which the specimens in reference 1 were machined.

EXPERIMENTAL SETUP

The experimental apparatus used to support the beam vertically is shown in figure 2. The major components include a

clamping block, test specimen, modally tuned instrumented impact hammer, non-contact eddy current probe, and x-z vernier. The test specimen is a flat laminate that is supported vertically as a cantilever beam in the clamping block. The specimen width in all cases was 1 inch. All specimens were 20 plies with a thickness of approximately 0.10 inches. To ensure that the specimens were uniformly clamped, tool steel rods are inserted into the main support block, with linear bearing inserted into the removable clamping block. The force hammer, model PCB 2496, is a modally tuned impact hammer which has various hardness removable tips. The non-contact eddy current probe, Kaman model KD2310-3U, is a motion transducer which is positioned near the tip of the specimen.

The signals from the eddy current probe and the instrumented force hammer are read into an IBM PC-AT using a MetraByte DAS16 A-D high speed data acquisition board. The data is manipulated using the Signal Technologies Interactive Laboratory Software version 6.1. The loss factor is determined using the half power band width method.(9) The resonant frequency and the half power points are determined by performing a fourth order curve fit of the transfer function obtained from the ILS software. A schematic of the data acquisition system is included in figure 2. Details of this procedure are given in reference 10.

SPECIMEN GEOMETRY

All samples used in this investigation were fabricated with

20 plies of unidirectional prepreg material. Two 12 x 12 in. plates were fabricated of each material system. This panel size was chosen so that specimens for both static mechanical properties and damping loss factor could be machined from each panel.

To determine the loss factor as a function of frequency, composite beams of varying length are required. The initial beam length for each orientation was approximately 10 in. Once testing was performed using this beam, one end was machined to a predefined length. This results in a change in the first resonant frequency for the beam. By varying the length of the test beams then, the loss factors at various frequencies could be determined. The current range of interest are low frequencies, below 1000 Hz.

The beam lengths required to achieve a particular first resonant frequency can be determined using the following equation for a clamped-free beam.

$$\omega_n = \left(\frac{k_n\ t}{L^2} \right) \sqrt{\frac{E}{12\rho}} \qquad (2)$$

where ω_n is the frequency of the n^{th} mode, t is the laminate thickness, L is the beam length, E is the bending stiffness, ρ is the density and k_n is the coefficient for the n^{th} frequency.(8) The mechanical properties required in equation 2 were determined experimentally using the procedures given in reference 11.

SPECIMEN FABRICATION

The unidirectional composites constructed for this program were made from unidirectional prepreg tape. The materials used were glass/epoxy (Hercules S2-Glass/3501-6), graphite/epoxy (Hercules AS4/3501-6). The glass and graphite/epoxy specimens (fiber volume fraction is 65%) were fabricated in-house according to the manufacturers recommended cure cycle.

All panels were trimmed and cut to size on a surface grinder with a diamond cutting wheel to a width of approximately 1 in. Specimens were then ultrasonically inspected to verify that no damage was present due to either processing or machining. Any specimen which was suspect after ultrasonic inspection was not used in the damping investigation. A 1 x 1 in. piece of aluminum foil was then bonded to one end of each specimen. This was necessary to provide a conducting surface which could be monitored by the non-contact eddy current probe.

CLAMPING APPARATUS

The fixturing used to clamp the specimen was a modification from that given in reference 1 where the specimen was clamped in a horizontal position, shown in figure 3.

Many of the same features are used for both test configurations. To ensure that no extraneous loss mechanisms would occur from the creation of damage in the material, guide rails, consisting of tool steel rods, were mounted into the main clamp block with linear bearings mounted into the movable clamp

block. This feature insures that there is no eccentric loading on the clamped specimen. Ultrasonic inspection of the specimens after testing indicated that no specimen damage results from the specimen clamping. In addition, to minimize frictional losses, the specimens were clamped in the fixture to a torque of 10 ft-lb with a ply of TX-1040 peelply placed between the specimen and fixture.

The main difference between the fixturing used in this investigation and that used in reference 1 is the steel plate used to to clamp the specimen in the vertical position as shown in figure 2. This vertical support plate was 8 x 14 x 1.25 in. which was bolted to the 12 x 16 base plate. The entire apparatus was then bolted to a 3 in. thick steel plate with dimensions 3 x 3 ft. This plate is attached to a load frame via isolation springs.

Because of the possibility of the vertical support structure being excited into a resonant vibration, tests were conducted to determine the resonant frequency of this vertical support structure. This was done by exciting the fixture with the instrumented impact hammer and determining the loss factor by the half power band width method. The resonant frequency of the fixture was determined to be 22.65 Hz. with a standard deviation of 0.27 Hz. Although, the excitation of the specimen should cause only a minimal excitation of the fixture, all composite testing was done at frequencies which were different than this resonant

frequency or its multiples. Table 1 lists these frequencies.

EDDY CURRENT PROBE

To minimize any adverse effects of the added mass of an accelerometer to the beam tip, a non-contact eddy current probe was used to monitor beam tip displacements. This probe was a Kaman Instrumentation Model KD2310-3U which can detect and monitor both magnetic and nonmagnetic materials. The probe was attached to a plexiglas holder which was attached to an x-z vernier. The vernier is bolted to a breadboard baseplate to provide stability and ease of positioning with respect to the specimen.

The signals from the transducer are first calibrated with a similar specimen using a micrometer calibration fixture. The eddy current probe was calibrated so that at a displacement of ± 0.040 in., the output recorded by the A-D data acquisition board was ± 1 volt. The output of the eddy current probe was then determined at various positions between +0.04 and -0.04 in. A linear fit was then determined for the data and used in the conversion of the voltage output to displacement in the data acquisition computer program. The data from this calibration and the linear fit are given in figure 4.

INSTRUMENTED FORCE HAMMER

The specimens were excited using a modally tuned impact hammer. This is a PCB Piezotronics, Inc., Model No. 086B01

impulse hammer with a 0-100 lb. force output. The hammer is supplied with impact tips of varying hardness. It was observed in the testing that for the higher frequencies of test, the harder tips were required to ensure a reproducible tip displacement vibration.

DATA REDUCTION

The output signals from the instrumented force hammer and the eddy current probe were input to an IBM PC-AT. This analogue signal was converted using the MetraByte DAS16 A-D data acquisition board and stored in a file. This data was then manipulated using Interactive Laboratory Software by Signal Technologies, Inc. An FFT of the displacement vs. time information is then performed. The FFT in the vicinity of the resonant frequency is then extracted from the file and stored as the left and right side of the peak value. This is readily recognized by the 2π phase shift in the FFT.

A fourth order orthogonal curve fit is then made of the right and left side values of the FFT. The coefficients are recorded and used as input into a computer routine which determines the intersection of the two curves and the values on each of the curves which are .707 of the value at this intersection, known as the half power points. The loss factor is then determined using the half power band width method as

$$\eta_n = \frac{\Delta f}{f_n} = \frac{(f_2 - f_1)}{f_n} \qquad (3)$$

where Δf is the bandwidth at the half-power points, f_2 and f_1 are the frequencies of the half-power points and f_n is the resonant frequency for the n^{th} mode. It should be noted that in general, an excellent agreement was obtained between the experimentally determined resonant frequency and that determined using equation 2. The coefficient of variation between the experimentally determined values of the resonant frequencies were less than 5%.

A more detailed description of the experimental procedure is given in reference 10. In addition, details of the calibration of the test fixturing used in this investigation is presented. The results from this testing were that other sources of energy dissipation are minimized by the apparatus used in the investigation.

RESULTS AND DISCUSSION

In this section the experimental results for the vertical orientation are presented and compared to those obtained previously with the test specimen oriented in the horizontal position. A discussion on the validity of the test results then follows along with discussion on the loss factor of the glass and graphite/epoxy composite materials. From the experimental program, the influence of fiber and orientation as a function of frequency are discussed.

The numerical results from the testing are presented in tabulated form in Appendices A-D. Results for the glass/epoxy 20

ply samples for the 0 and 90 degree samples are presented in Appendices A and B, respectively, for both the vertical and horizontal orientations. The graphite/epoxy results for the 0 and 90 degree 20 ply samples are presented in Appendices C and D, respectively, for both the vertical and horizontal orientations.

INFLUENCE OF TEST CONFIGURATION

The two test configurations are discussed. The first oriented the cantilever beam in the horizontal position, which is the orientation normally utilized by other investigators. The second configuration supported the cantilever beam specimen vertically. The utilization of the latter configuration was to minimize gravitational effects and eccentric loading which may result in addition damping sources.

Figures 5 and 6 show the experimentally determined damping loss factor for the 0 degree S2 Glass/3501-6 material with the specimens oriented in the horizontal and vertical positions, respectively. In the horizontal orientation, the maximum in loss factor occurred at the lowest test frequency. As the test frequency increased, the resultant loss factor decreased and remained at approximately the same value up to the maximum test frequency.

These results are contrary to those expected. A typical viscoelastic material will show an increase in loss factor with frequency. One possible explanation for the experimental results can be related to the dimensions of the test specimen. The beam

length decreases with increasing frequency. The lowest frequency corresponds to the longest beam length. The modulus of the material is approximately 8.1 Msi. At the longer lengths, the stress distribution through the thickness at the clamped end is larger than for the shorter lengths, due to the weight of the beam. For the same tip displacements, the stress variation through the thickness of the beam is less, the longer the beam. This variation in stress level may vary the energy dissipation.

A second explanation may be the result of the gravitational effects. As the beam is displaced from its equilibrium position, its acceleration, and hence its displacement, is a combination of the excitation force and the gravitational force. As the beam is displaced downward, this effect is additive. However, as the beam displaces upward, the restoring force must overcome gravity which reduces the magnitude of the tip displacement. The result is that there is an apparent damping increase which is the sole result of the beam configuration. For the longer beams, for the same displacement, the ratio of the restoring force to the gravitational force is less. The resultant apparent damping is therefore a combined material damping and configurational damping.

This effect is most readily evident in the S2 Glass/3501-6 0 degree orientation. In the vertical test configuration, the loss factor is shown to be relatively constant up to a frequency of approximately 700 Hz, as shown in figure 6. At higher frequencies, the loss factor increases, as one would normally

expect for a viscoelastic material. This is in contrast to the results presented earlier for the horizontal configuration where there was a decrease in loss factor with increasing frequency. It should be noted that the loss factor determined for the frequency range of approximately 200 to 700 Hz. for both configurations are very similar. There may be a critical beam length whereby gravitational effects become negligible.

Differences in the loss factor for the two test configurations also occur for the 90 degree S2 Glass/3501-6 specimens. At low frequencies, up to approximately 80 Hz., the horizontal configuration has a higher loss factor than the vertical configuration as seen in figures 7 and 8 respectively. As the frequency increases, and beam length decreases, the results are approximately the same, in the frequency range of 80 to 300 Hz. At the higher frequencies, however, vertical configuration had a higher loss factor. The results for the vertical orientation show trends that would be anticipated for a general viscoelastic material. The decrease in loss factor at the low frequency range for the horizontal orientation is probably due to the gravitational and stress effects that were noted previously.

For the 0 degree graphite/epoxy material, the specimen configuration had little effect on the loss factor over the frequency range tested. The results for the horizontal and vertical orientations are shown in figures 9 and 10, respectively. These results show that there may be a stiffness

criteria for determination of the beam configuration that must be used in the determination of loss factor for composites. As the beam stiffness increases, the gravitational and/or stress effects may be minimized, allowing either configuration to be used. This is further supported in the calibration work given in reference 10. Here, the aluminum beam had a width of 1 inch and thickness of 0.125 in. With a stiffness of 15 Msi, there was minimal beam displacement in the static position for all beam lengths used. Results using this configuration matched those that were expected analytically over the entire frequency range tested.

The most significant variation in test results occurred for the 90 degree AS4/3501-6 graphite/epoxy. In the horizontal configuration, shown in figure 11, the loss factor at the low frequencies was greater than any of the other systems tested. As the frequency of test was increased, the was a monotonic decrease in loss factor. In the vertical orientation, shown in figure 12, the loss factor at frequencies less than 60 Hz. were up to a factor of 3 less than those determined with the horizontal configuration. The variation of loss factor with frequency tested in the vertical position showed an initial increase with increasing frequency up to approximately 200 Hz. In the frequency range of 200 to 700 Hz., the loss factor remained approximately the same.

By comparing these results with the elastic properties of the various material systems, an interesting results arises. The 90

degree AS4/3501-6 had the lowest axial stiffness of the materials investigated. This was also the material which showed the most significant variation in loss factor results when the tested configuration was changed. The variation was maximum at the longer beam lengths, although the loss factor values determined at the higher frequencies were approximately equal.

The 90 degree S-2 glass/3501-6 had an axial stiffness which was approximately double the 90 degree AS4/3501-6. As such, one would expect that the variation in loss factor for the glass material between the two configurations would be similar to that of the graphite. The variation in results, however, were not as large. At the low frequencies, and therefore the longer beam lengths, the loss factor for the horizontal configuration was approximately 40% greater than the results obtained using the vertical orientation. At the mid range frequencies the results were approximately equal. At the higher frequencies, the loss factor results using the vertical orientation were approximately 40% greater than those obtained using the horizontal configuration. Although the trend in loss factor variation with frequency using the vertical configuration followed what would be expected for a general viscoelastic material, no explanation is offered for the differences noted between the glass and graphite composite systems.

In the analysis that follows, the discussion will be limited to the results from the testing in the vertical orientation. The

reason for this is that it is the author's opinion that these results are a more accurate representation of the composite material damping loss factor. In addition, a detailed discussion on the results using the horizontal test configuration has been previously published in reference 1.

INFLUENCE OF FIBER PROPERTIES

The influence of fiber properties can be assessed for both the 0 and 90 degree epoxy matrix composite materials. The fiber characteristics of the graphite and glass are significantly different. Their differences exist in both their microstructure, mechanical properties and physical dimensions.

Microstructurally, the glass is an isotropic fiber whereas the graphite is highly anisotropic. The isotropic structure of glass results in mechanical properties which are equivalent in all directions. Carbon fibers are composed of long ribbons of turbostratic graphite oriented more or less in the fiber direction.(12) These ribbons are grouped together in stacks about 20 Å thick.(12) The normals to the basal plane of the stacks are randomly oriented perpendicular to the fiber axis, i.e. diffraction patterns of carbon fibers have fiber texture. Consequently, carbon fibers have high stiffness and strength only in the fiber direction, in which carbon-carbon covalent bonds can bear the load. The turbostratic graphite ribbons are held together by van der Waals bonds, resulting in low strength and stiffness transverse to the fiber axis.

These differences in fiber characteristics result in significant differences in material properties. For the 0 degree configuration, the graphite/epoxy has a modulus approximately 2.5 times greater than the glass/epoxy. All mechanical properties in the 0 degree orientation are fiber dominated. For an equivalent input excitation force, the load experienced by the matrix will be significantly different in the two composite systems. In the 90 degree orientation, the glass/epoxy has a modulus which is approximately 60% greater than the graphite/epoxy. In this configuration, the graphite fiber can be more readily deformed and may contribute to the damping of the composite. For the glass/epoxy, any additional energy dissipation experienced in the 90 degree orientation compared to the 0 degree orientation would be attributed to the damping of the matrix material.

The 90 degree glass/epoxy and graphite/epoxy have loss factors which are approximately equal in the frequency range of 20 to 400 Hz. Both show an increase in loss factor in this frequency range. For increasing frequencies, the loss factors of these two systems diverge with the loss factor of the glass/epoxy increasing with increasing frequency while the graphite/epoxy remains approximately the same.

The results for the glass/epoxy are similar to the results that one might expect for the resin alone, i.e. an increase in loss factor with increasing frequency. With the graphite/epoxy

system, there may be changes in the fiber loading as the frequency increases due to the fiber microstructure which may be causing the constant loss factor in the frequency range tested.

For the 0 degree orientation, the glass/epoxy and graphite/epoxy systems have loss factors that are approximately equal within the scatter of the experimental data up to frequencies of approximately 800 Hz. At frequencies above 800 Hz., the loss factor for the glass/epoxy increases, whereas it is anticipate that the loss factor for the graphite/epoxy would follow the linear trend established at the lower frequencies. The 0 degree graphite/epoxy trends are probably due to the high stiffness of the fiber.

INFLUENCE OF FREQUENCY

The frequency range tested in this program was up to 1000 Hz. For both the 0 and 90 degree configuration for the glass and graphite composite fiber systems, there was, in general, an increase in loss factor with frequency. The increase in each case was different depending on the orientation and fiber type. Only in the 0 degree graphite/epoxy case did the increase appear to be linear.

This result was anticipated for these materials systems based on the assumption that they can be considered a general viscoelastic material. It is also not surprising that the frequency effect varied with fiber type. As was discussed previously, the fiber mechanical and physical characteristics are

significantly different. As such, the manner and mechanisms by which each material dissipates energy should vary, resulting in a complex variation in loss factor with frequency.

INFLUENCE OF FIBER ORIENTATION

For both the glass and graphite epoxy systems, in the 90 degree orientation, the loss factor was greater than that determined for the 0 degree orientation. For the glass/epoxy material, the loss factor for the 90 degree orientation was approximately 2 times that of the 0 degree orientation up to a frequency of approximately 200 Hz. For increasing frequency, the loss factor of the 90 degree orientation increased more rapidly than the 0 degree orientation, showing a 3 to 4 times increase in loss factor. This trend for the 90 degree orientation follows the results that one would obtain using a DMTA for loss factor determination of the matrix. In the 90 degree orientation, since the matrix is the predominant load carrying component, the damping loss factor should follow the trend of the matrix alone.

For the graphite/epoxy material, the loss factor for the 90 degree orientation was approximately 2 times that of the 0 degree orientation over the frequency range tested. The loss factor for the 90 degree orientation for the graphite/epoxy was anticipated to be similar to that of the glass. The graphite/epoxy, however, did not show the same magnitude of loss factor increase as the glass/epoxy in the frequency range tested. The reason for the difference in the loss factor for the 90 degree orientation

between the graphite and glass composite systems may be due to the mechanical and physical differences in the fibers. In addition, there is a difference in the residual stresses in these two systems which may also account for the variation.

In addition to the 0 and 90 degree orientations, the AS4/3501-6 was also tested with a ± 45 degree orientation. This configuration was used to obtain a shear loss factor, η_{12}. The results from the testing are given in Appendix E and are shown in graphical form in figure 13.

The results from this orientation show an increase similar to that obtained with the 0 degree AS4/3501-6. This modest increase in loss factor appears to be contrary to the results obtained in the literature for this orientation (13-15). The loss factors reported in references 13-15 for the ± 45 orientation are on the order of a factor of 2 to a factor of 5 times greater than the results obtained herein. These results may be the result of the specimen orientation, a horizontal orientation for the literature results, the specifics of the clamping, or possibly specimen quality, all of which could add to the apparent material loss factor.

The results indicate that the loss factor of the matrix material dominates the response of the composite. Even though the ± 45 degree configuration should place the material in a shear when subjected to a bending moment, the contribution in shear

appears to be less than the loss provided by the matrix in the 90 degree orientation.

CONCLUSIONS

Material damping of continuous fiber organic matrix composites is experimentally determined using a cantilever beam test specimen geometry and an impulse excitation technique. Two orientations are utilized, a vertical and horizontal cantilever beam orientation. The damping loss factor for 0 and 90 degree glass/epoxy (Hercules S2 Glass/3501-6) and graphite/epoxy (Hercules AS4/3501-6) are measured. The results obt[illegible]ng the vertical orientation appear to be more representative of this type of material. Damping is found to be effected by fiber type, fiber orientation and frequency of test. Damping increases with increasing frequency for both orientations. Damping of the 90 degree specimens are greater than from the 0 degree orientation. The glass/epoxy material is a better damping material than the graphite/epoxy over the entire frequency range and in both fiber orientations. The loss factor obtained from the AS4/3501-6 in the $\pm$45 degree orientation is between the results of the 0 and 90 degree orientation.

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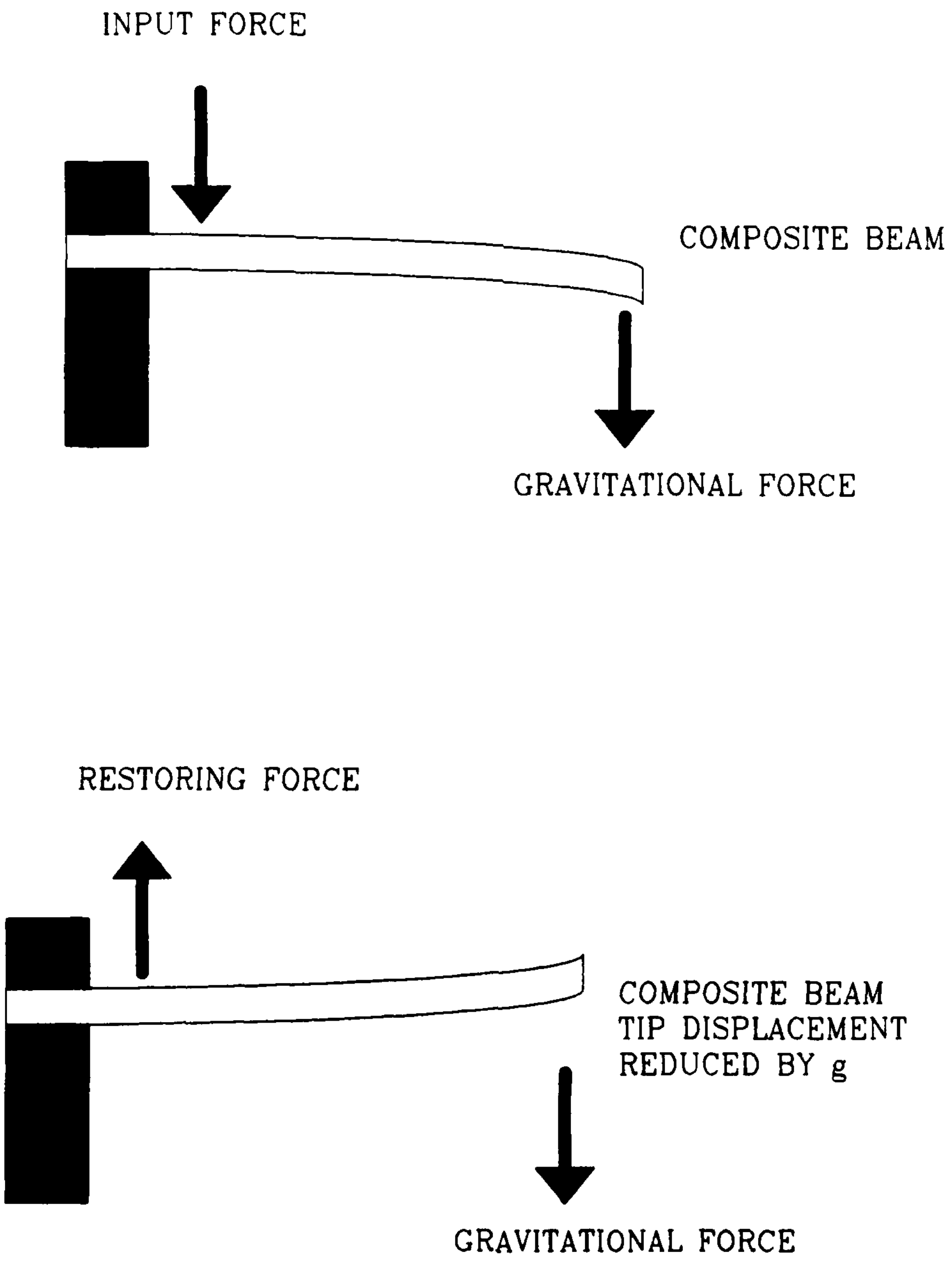


Fig: 1: Diagram of beam displacement under the influence of gravity

Figure 2: Schematic of the appartus for testing the vibration damping loss factor of composites using a vertically oriented cantilever beam.

Figure 2a: Schematic of experimental appartus

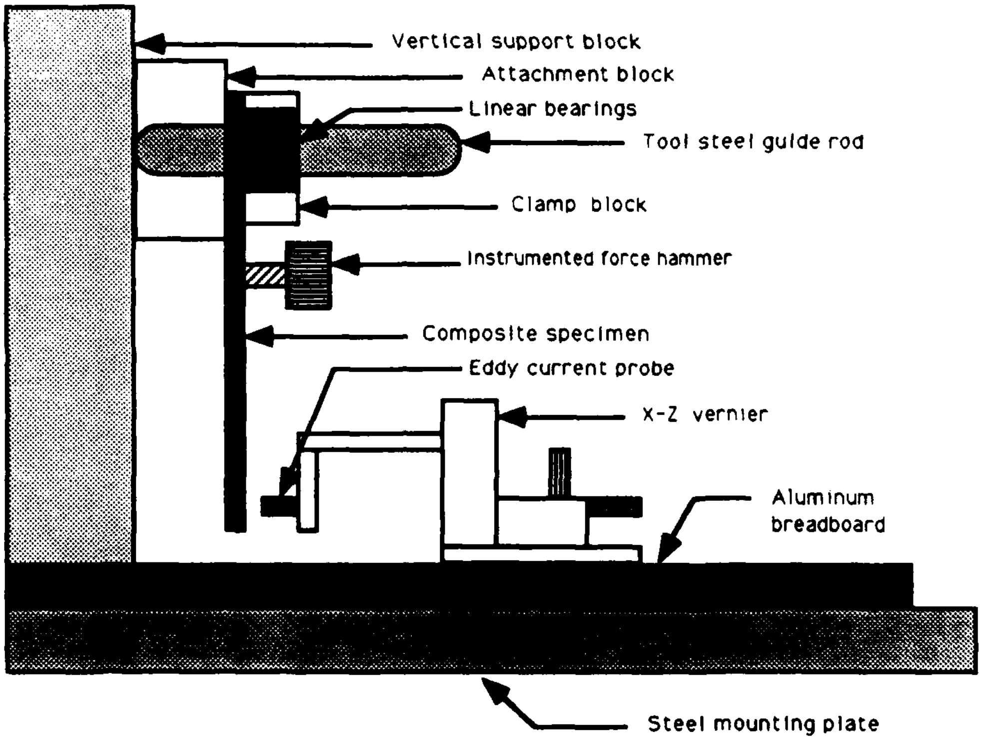
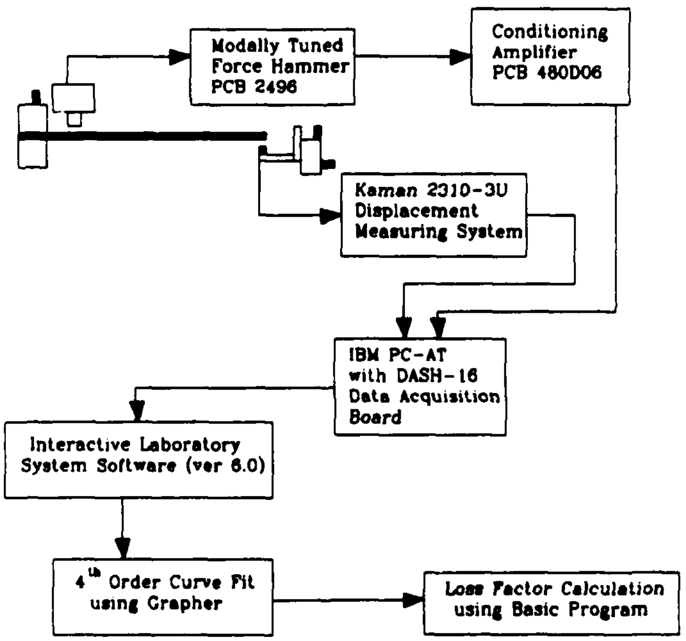


Figure 2b: Schematic of data acquisition system



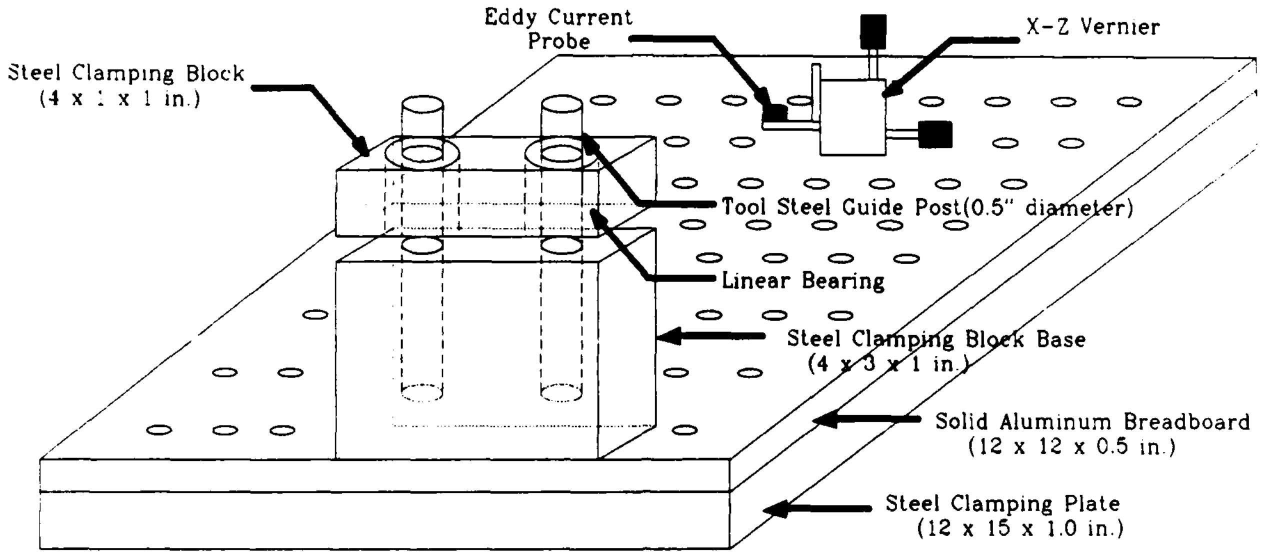


Figure 3: Schematic of experimental apparatus for testing the vibration damping loss factor of composites using a horizontally oriented cantilever beam

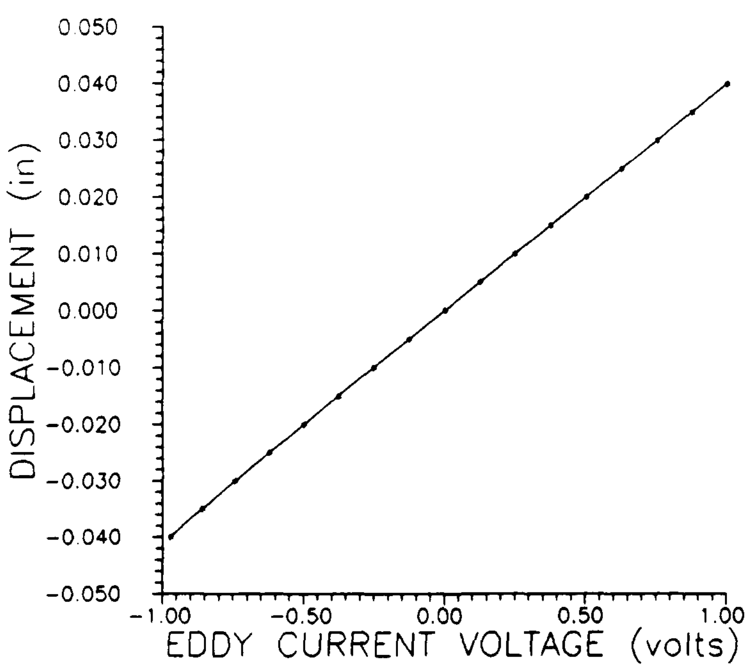


Figure 4: Calibration of eddy current voltage output vs. displacement

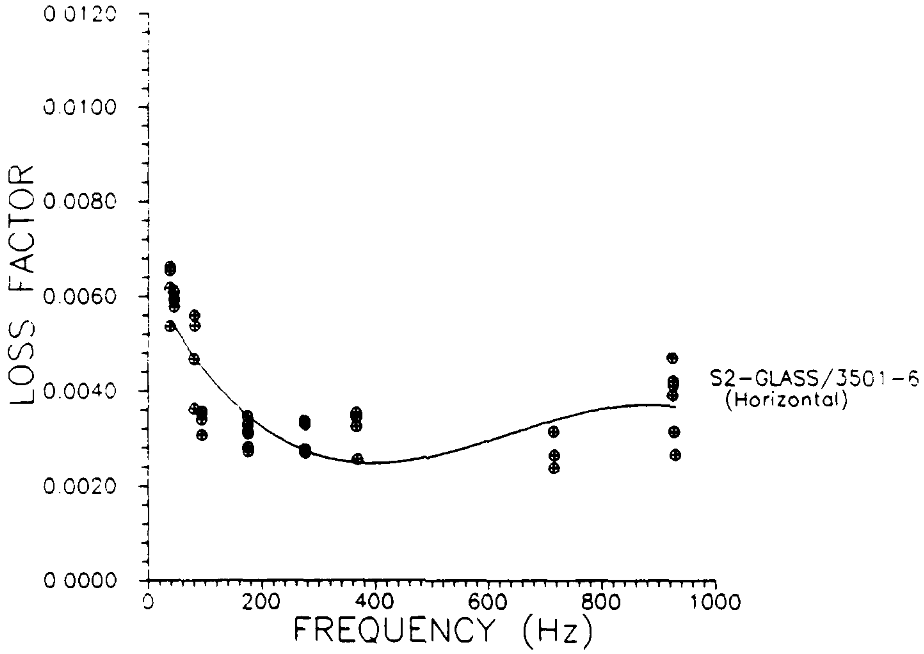


Fig. 5: Experimentally determined vibration damping loss factor vs. frequency for 0 degree glass/epoxy (Hercules S2-Glass/3501-6) using the horizontal cantilever beam orientation

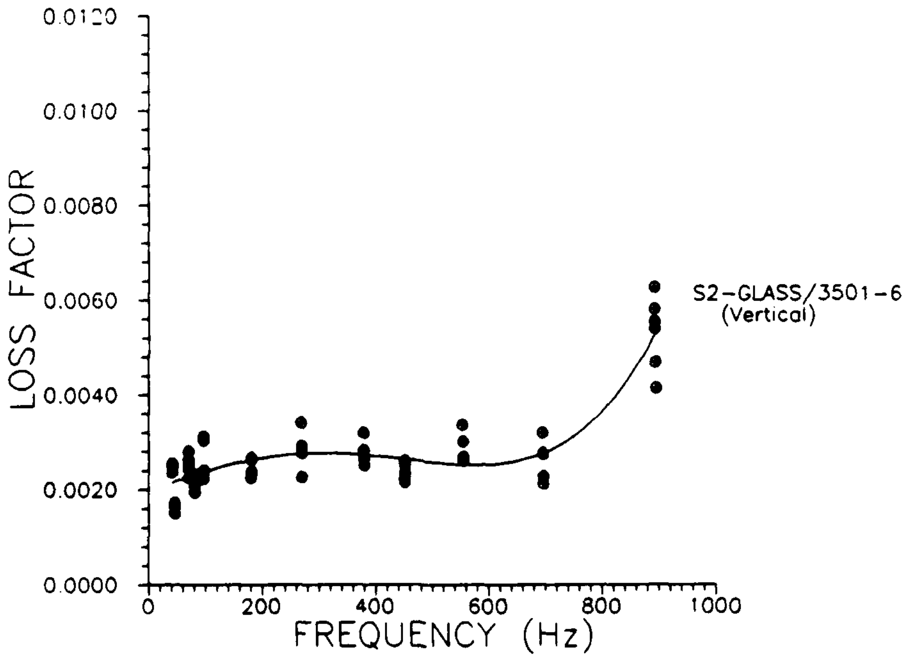


Fig. 6: Experimentally determined vibration damping loss factor vs. frequency for 0 degree glass/epoxy (Hercules S2-Glass/3501-6) using the vertical cantilever beam orientation

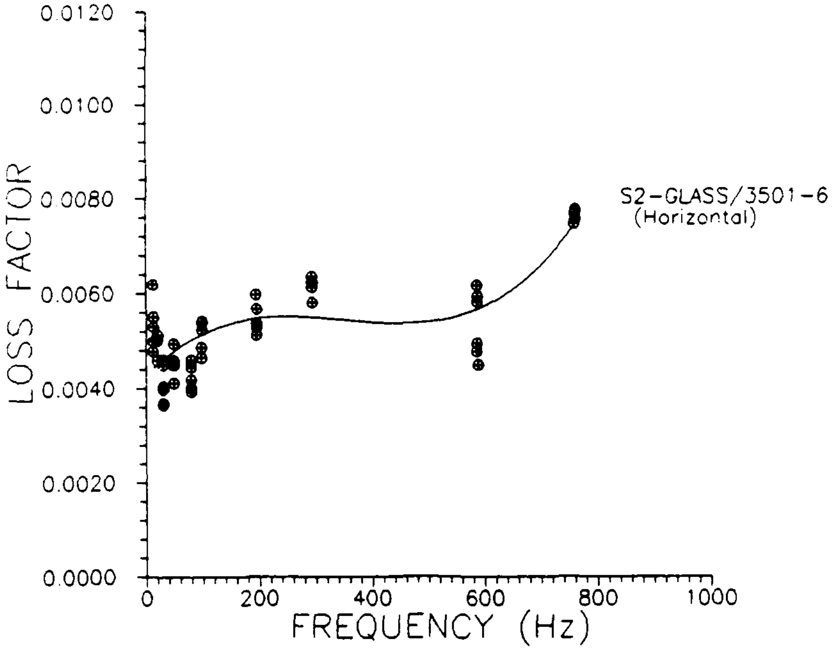


Fig. 7: Experimentally determined vibration damping loss factor vs. frequency for 90 degree glass/epoxy (Hercules S2-Glass/3501-6) using the horizontal cantilever beam orientation

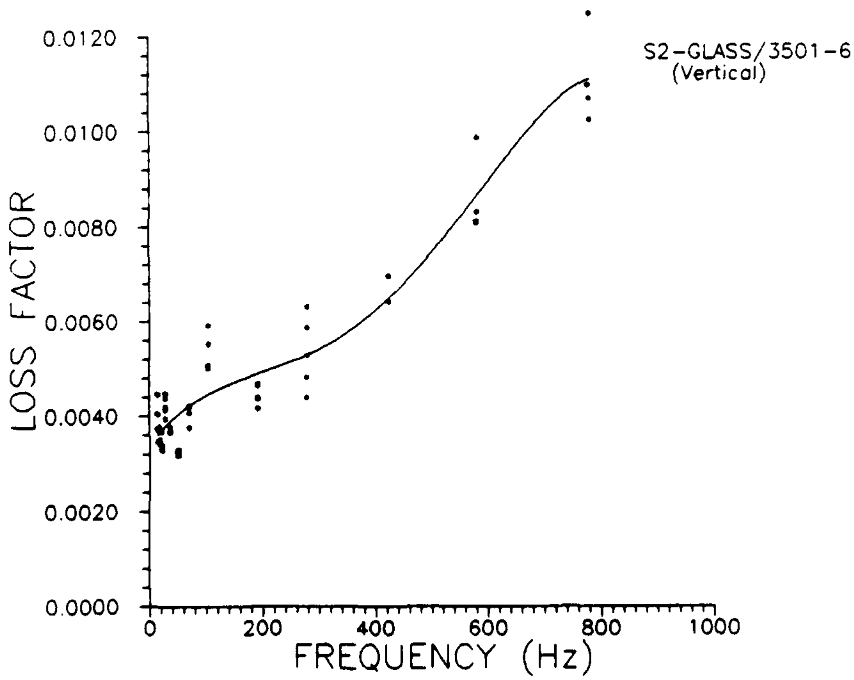


Fig. 8: Experimentally determined vibration damping loss factor vs. frequency for 90 degree glass/epoxy (Hercules S2-Glass/3501-6) using the vertical cantilever beam orientation

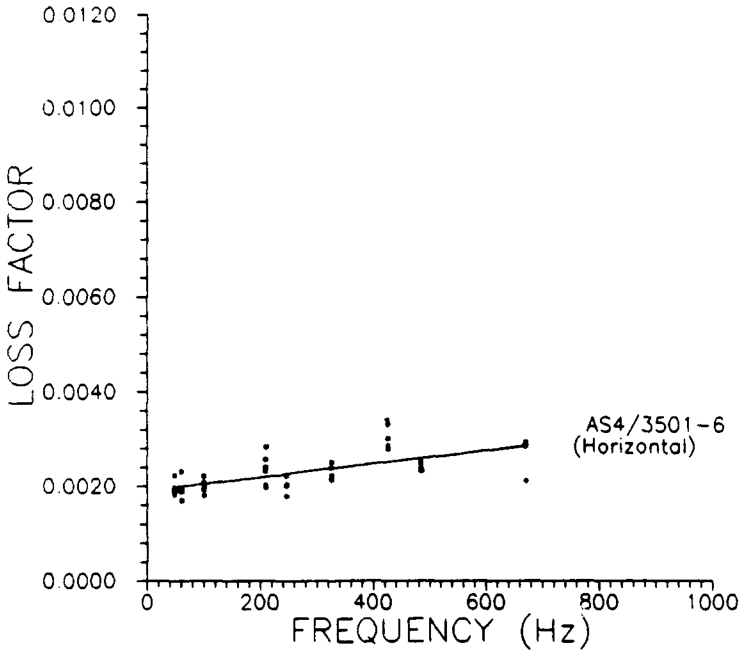


Fig. 9: Experimentally determined vibration damping loss factor vs. frequency for 0 degree graphite/epoxy (Hercules AS4/3501-6) using the horizontal cantilever beam orientation

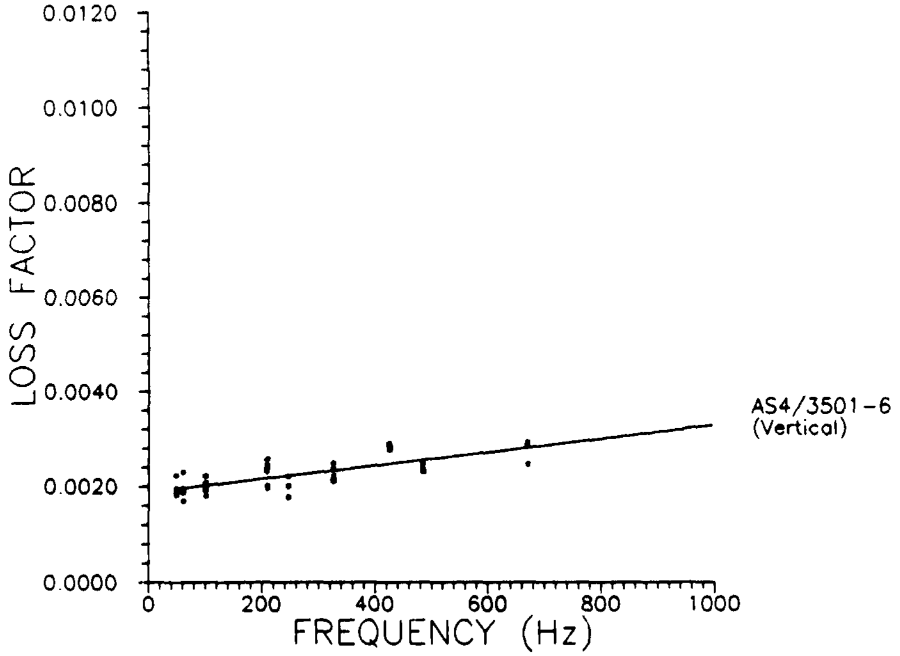


Fig. 10: Experimentally determined vibration damping loss factor vs. frequency for 0 degree graphite/epoxy (Hercules AS4/3501-6) using the vertical cantilever beam orientation

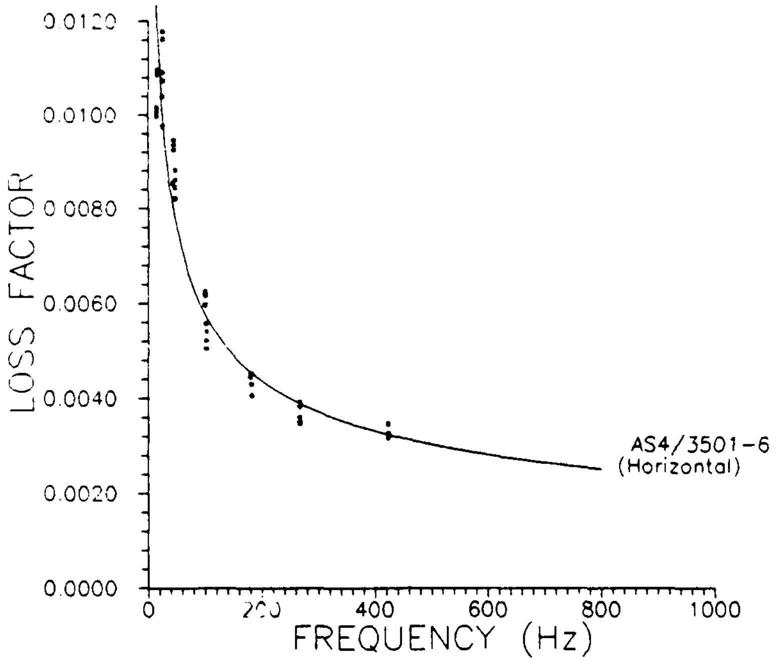


Fig. 11: Experimentally determined vibration damping loss factor vs. frequency for 90 degree graphite/epoxy (Hercules AS4/3501-6) using the horizontal cantilever beam orientation

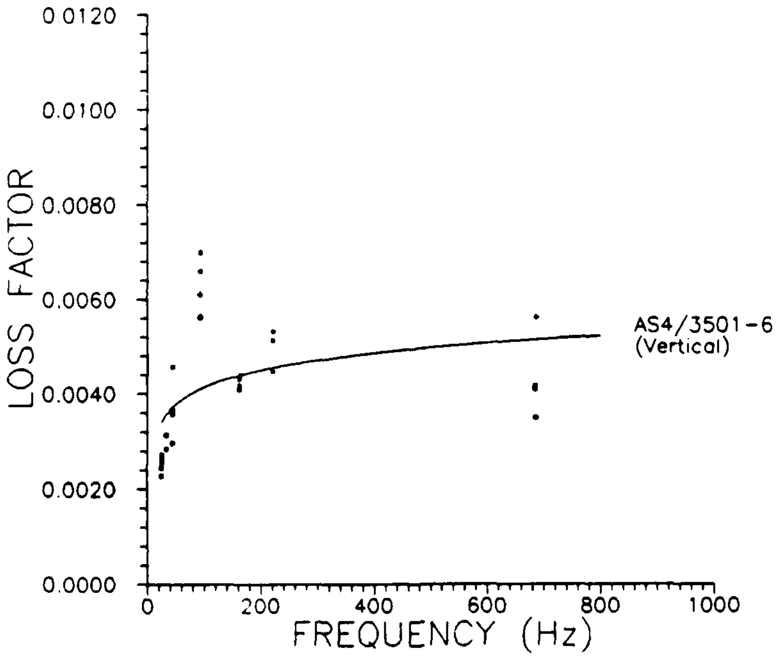


Fig. 12: Experimentally determined vibration damping loss factor vs. frequency for 90 degree graphite/epoxy (Hercules AS4/3501-6) using the vertical cantilever beam orientation

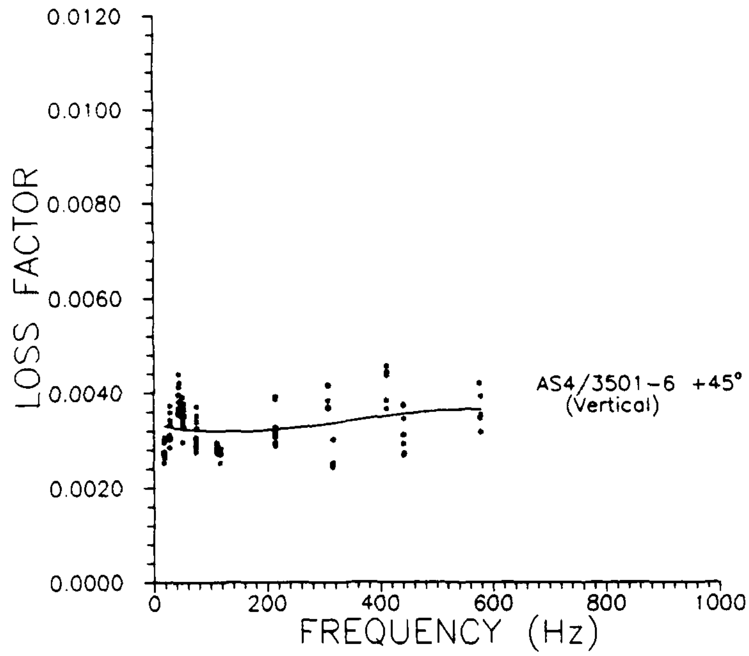


Fig. 13: Experimentally determined vibration damping loss factor vs. frequency for ± 45 degree graphite/epoxy (Hercules AS4/3501-6) using the vertical cantilever beam orientation

TABLE 1

Mode No.	Resonant Frequency (Hz.)
1	22.65
2	56.70
3	94.89
4	132.83
5	170.78
6	208.73
7	246.67
8	284.63
9	322.58
10	360.53

Table A-1: S2 Glass/3501-6 $[0]_{20}$ glass/epoxy damping data

Vertical Orientation

SPECIMEN BEAM LENGTH (in.)	FIRST RESONANT FREQUENCY (Hz)	DAMPING LOSS FACTOR ($\times 10^{-4}$)
8.50	41.10	25.5709
8.50	41.10	25.2502
8.50	41.10	25.1802
8.50	41.11	24.5709
8.50	41.12	23.6113
8.00	46.22	16.5152
8.00	46.22	17.2201
8.00	46.22	16.2904
8.00	46.24	15.0301
8.00	46.24	15.1905
6.50	69.92	26.4575
6.50	69.94	24.5360
6.50	69.94	28.1161
6.50	69.96	22.6287
6.50	69.98	25.4939
6.00	81.72	22.5998
6.00	81.77	23.2703
6.00	81.78	20.8746
6.00	81.80	19.4362
6.00	81.81	19.6804
5.50	96.80	31.2888
5.50	96.82	30.4749
5.50	96.92	24.1050
5.50	96.93	24.0694
5.50	96.94	22.3730
4.00	180.83	23.8945
4.00	180.90	26.8021
4.00	180.91	23.4307
4.00	180.94	26.4636
4.00	181.04	22.5874
3.25	269.52	34.1779
3.25	269.76	29.2937
3.25	269.82	28.6948
3.25	269.91	27.7835
3.25	270.20	22.7031
2.75	379.49	32.0061
2.75	379.63	28.3694
2.75	379.73	26.6739
2.75	379.84	26.5276
2.75	379.93	25.1668
2.50	451.54	23.5823
2.50	451.64	25.2665
2.50	451.68	26.1291
2.50	451.87	22.3877
2.50	452.17	21.5870

Table A-1: S2 Glass/3501-6 $[0]_{20}$ glass/epoxy damping data(cont)

Vertical Orientation

SPECIMEN BEAM LENGTH (in.)	FIRST RESONANT FREQUENCY (Hz)	DAMPING LOSS FACTOR ($x\ 10^{-4}$)
2.25	553.88	33.7322
2.25	554.74	30.2114
2.25	555.20	26.9739
2.25	555.26	26.1729
2.25	555.71	23.2719
2.00	694.96	32.0773
2.00	695.52	27.5777
2.00	695.70	27.7101
2.00	696.57	22.9039
2.00	696.81	21.2974
1.75	891.14	62.7510
1.75	891.58	58.1845
1.75	891.70	55.5741
1.75	891.92	54.1028
1.75	893.48	46.9676
1.75	895.01	41.5186

Table A-2: S2 Glass/3501-6 $[0]_{20}$ glass/epoxy damping data
Horizontal Orientation

SPECIMEN BEAM LENGTH (in.)	FIRST RESONANT FREQUENCY (Hz)	DAMPING LOSS FACTOR ($\times 10^{-4}$)
8.81	37.818	61.742
8.81	37.840	53.536
8.81	37.844	65.335
8.81	37.866	66.149
8.00	45.601	60.934
8.00	45.627	57.717
8.00	45.648	59.511
8.00	45.660	59.208
6.00	81.117	55.927
6.00	81.119	53.681
6.00	81.154	36.186
6.00	81.497	46.678
6.00	81.555	46.632
5.50	94.735	35.512
5.50	94.833	30.579
5.50	94.851	33.880
5.50	95.325	35.503
5.50	95.327	35.409
5.50	95.423	35.410
4.00	175.546	34.593
4.00	175.655	32.816
4.00	175.752	31.498
4.00	175.796	30.940
4.00	175.916	27.282
4.00	176.163	28.132
3.23	276.131	26.944
3.23	276.188	33.591
3.23	276.267	32.797
3.23	276.331	27.101
3.23	276.553	33.416
3.23	276.595	27.553
2.75	366.756	35.231
2.75	367.354	32.360
2.75	367.479	34.259
2.75	368.740	25.488

Table B-1: S2 Glass/3501-6 $[90]_{20}$ glass/epoxy damping data

Vertical Orientation

SPECIMEN BEAM LENGTH (in.)	FIRST RESONANT FREQUENCY (Hz)	DAMPING LOSS FACTOR ($\times 10^{-4}$)
11.00	14.76	44.6698
11.00	14.77	40.4583
11.00	14.77	40.5193
11.00	14.78	34.5756
11.00	14.78	37.1940
10.00	17.64	37.7952
10.00	17.65	35.1942
10.00	17.94	37.1346
10.00	17.94	37.1450
10.00	17.96	34.3765
9.00	22.34	36.7044
9.00	22.35	32.8374
9.00	22.35	33.8367
9.00	22.35	33.7257
9.00	22.36	32.9918
8.00	28.47	44.8048
8.00	28.48	39.4298
8.00	28.48	42.0597
8.00	28.50	41.3477
8.00	28.50	43.8193
7.00	37.10	36.7474
7.00	37.10	36.5988
7.00	37.10	37.7842
7.00	37.11	36.8713
7.00	37.12	37.7863
6.00	50.26	32.7829
6.00	50.26	31.9276
6.00	50.26	32.9313
6.00	50.27	31.8425
6.00	50.27	32.1957
5.00	71.34	42.2737
5.00	71.35	40.6955
5.00	71.36	41.9180
5.00	71.36	42.2782
5.00	71.39	37.6081
4.00	104.12	59.2340
4.00	104.13	55.3379
4.00	104.13	50.2414
4.00	104.25	50.8540
4.00	104.26	55.3379
3.00	192.54	46.4671
3.00	192.58	44.0017
3.00	192.61	43.6559
3.00	192.63	46.8477
3.00	192.69	41.6094

Table B-1: S2 Glass/3501-6 $[90]_{20}$ glass/epoxy damping data(cont)

Vertical Orientation

SPECIMEN BEAM LENGTH (in.)	FIRST RESONANT FREQUENCY (Hz)	DAMPING LOSS FACTOR ($\times 10^{-4}$)
2.50	278.78	44.0891
2.50	278.84	48.2888
2.50	279.03	63.1837
2.50	279.03	58.8268
2.50	279.06	52.9885
2.00	423.83	69.5593
2.00	424.61	64.1371
2.00	424.75	60.7729
1.75	580.66	81.3521
1.75	580.88	81.0418
1.75	580.98	83.3434
1.75	581.07	98.8858
1.50	778.50	109.9265
1.50	779.85	125.0750
1.50	780.23	107.1298
1.50	781.34	102.6685

Table B-2: S2 Glass/3501-6 $[90]_{20}$ glass/epoxy damping data

Horizontal Orientation

SPECIMEN BEAM LENGTH (in.)	FIRST RESONANT FREQUENCY (Hz)	DAMPING LOSS FACTOR ($\times 10^{-4}$)
11.84	12.828	55.0280
11.84	12.795	49.9250
11.84	12.877	52.9645
11.84	12.816	47.7420
11.84	12.846	61.9003
9.52	19.966	50.3042
9.52	19.925	45.8076
9.52	19.898	50.1035
9.52	19.930	51.3104
7.77	29.990	36.7393
7.77	30.025	36.5254
7.77	29.946	44.9431
7.76	30.011	40.4229
7.76	30.017	45.9937
7.76	30.035	39.7218
6.03	49.234	45.8412
6.03	49.203	41.1675
6.03	49.202	45.1763
6.03	49.239	49.4467
6.03	49.186	44.9494
5.72	79.748	45.9238
5.72	79.794	44.4997
5.72	79.787	39.2332
5.72	79.731	41.8561
5.72	79.764	40.0591
4.25	97.926	46.4685
4.25	98.028	48.6442
4.25	97.835	52.3654
4.25	98.001	54.0049
4.25	97.981	54.1517
2.98	195.070	51.1757
2.98	194.748	52.8341
2.98	194.829	59.7262
2.98	194.596	53.6054
2.98	195.704	56.6583
2.45	293.976	62.3772
2.45	294.147	61.2320
2.45	294.633	62.2536
2.45	294.191	63.5808
2.45	294.696	58.0343

Table B-2: S2 Glass/3501-6 $[90]_{20}$ glass/epoxy damping data (cont)

Horizontal Orientation

SPECIMEN BEAM LENGTH (in.)	FIRST RESONANT FREQUENCY (Hz)	DAMPING LOSS FACTOR ($\times 10^{-4}$)
1.73	585.672	47.5699
1.73	588.000	44.7396
1.73	586.459	49.2601
1.73	586.070	61.5899
1.73	586.823	58.0462
1.73	587.304	59.1875
1.50	758.712	74.7027
1.50	759.150	76.9423
1.50	760.485	75.8990
1.50	760.688	77.6526
1.50	760.784	78.3620

Table C-1: AS4/3501-6 $[0]_{20}$ graphite/epoxy damping data
Vertical Orientation

SPECIMEN BEAM LENGTH (in.)	FIRST RESONANT FREQUENCY (Hz)	DAMPING LOSS FACTOR ($\times 10^{-4}$)
10.34	48.54	18.256
10.34	48.54	19.676
10.34	48.54	22.172
10.34	48.57	18.954
10.34	48.58	19.335
10.34	48.59	19.236
9.38	60.42	23.003
9.38	60.45	19.005
9.38	60.52	19.223
9.38	60.55	17.455
9.38	60.60	18.437
7.25	100.30	20.004
7.25	100.32	19.431
7.25	100.34	21.967
7.25	100.61	18.111
7.25	100.65	19.421
5.00	209.22	23.206
5.00	209.28	25.054
5.00	209.34	24.570
5.00	209.53	24.070
5.00	209.64	20.222
5.00	209.66	20.190
4.50	246.20	22.244
4.50	246.40	20.975
4.50	246.52	18.821
4.50	246.53	20.007
4.00	325.75	20.902
4.00	326.00	21.107
4.00	326.32	22.989
4.00	326.54	24.324
4.00	326.64	22.866
3.50	424.87	28.963
3.50	425.13	28.051
3.50	425.27	28.040
3.50	425.50	28.421
3.50	425.82	27.664
3.25	484.80	25.858
3.25	484.87	25.021
3.25	484.95	24.007
3.25	485.01	23.910
3.25	485.11	23.885
2.75	668.34	28.696
2.75	668.72	28.554
2.75	668.80	29.153
2.75	670.50	25.111

Table C-2: AS4/3501-6 $[0]_{20}$ graphite/epoxy damping data

Horizontal Orientation

SPECIMEN BEAM LENGTH (in.)	FIRST RESONANT FREQUENCY (Hz)	DAMPING LOSS FACTOR ($\times 10^{-4}$)
10.34	48.54	18.156
10.34	48.54	19.645
10.34	48.55	22.276
10.34	48.58	18.868
10.34	48.59	19.315
10.34	48.59	19.130
9.38	60.41	23.053
9.38	60.43	19.605
9.38	60.53	19.173
9.38	60.54	16.955
9.38	60.62	18.779
7.25	100.27	20.780
7.25	100.32	19.209
7.25	100.35	22.140
7.25	100.62	18.021
7.25	100.66	19.864
5.00	209.19	23.192
5.00	209.29	25.720
5.00	209.38	28.282
5.00	209.41	24.070
5.00	209.47	20.255
5.00	209.64	19.726
4.50	246.15	22.164
4.50	246.37	20.258
4.50	246.48	17.846
4.50	246.49	20.121
4.00	325.73	21.309
4.00	326.00	21.246
4.00	326.26	23.848
4.00	326.53	24.942
4.00	326.58	22.217
3.50	424.87	34.102
3.50	425.10	33.092
3.50	425.21	30.055
3.50	425.48	28.538
3.50	425.80	27.843
3.25	484.70	25.111
3.25	484.81	24.265
3.25	484.90	23.703
3.25	484.99	23.309
3.25	485.01	23.179

Table C-2: AS4/3501-6 $[0]_{20}$ graphite/epoxy damping data

Horizontal Orientation

SPECIMEN BEAM LENGTH (in.)	FIRST RESONANT FREQUENCY (Hz)	DAMPING LOSS FACTOR ($\times 10^{-4}$)
2.75	667.86	35.048
2.75	667.98	34.840
2.75	669.01	29.276
2.75	668.44	28.531
2.75	668.77	28.512
2.75	668.82	29.357
2.75	670.49	21.107

Table D-1: AS4/3501-6 $[90]_{20}$ graphite/epoxy damping data

Vertical Orientation

SPECIMEN BEAM LENGTH (in.)	FIRST RESONANT FREQUENCY (Hz)	DAMPING LOSS FACTOR ($x\ 10^{-4}$)
9.50	18.18	30.9434
9.50	18.18	32.3631
9.50	18.18	32.7127
9.50	18.18	35.8768
9.50	18.19	35.4310
8.00	25.04	26.3836
8.00	25.04	27.3488
8.00	25.05	25.7960
8.00	25.05	24.6296
8.00	25.06	22.9090
7.00	33.24	31.3953
7.00	33.26	31.3953
7.00	33.27	31.4599
7.00	33.28	31.3736
7.00	33.30	28.5138
6.00	43.80	36.8334
6.00	43.85	45.7812
6.00	43.90	35.8354
6.00	44.02	29.7226
4.00	93.31	66.0126
4.00	93.41	69.9726
4.00	93.43	61.1306
4.00	93.55	56.4754
4.00	93.57	56.1898
3.00	163.04	40.9574
3.00	163.07	43.3269
3.00	163.12	43.9761
3.00	163.18	41.1822
3.00	163.21	41.8111
2.50	220.77	51.4223
2.50	220.90	44.8233
2.50	221.69	53.2566
1.88	422.35	34.6594
1.88	422.54	31.6445
1.88	422.75	32.8739
1.88	423.15	32.1890
1.50	684.59	40.9659
1.50	684.89	35.1242
1.50	685.00	41.7647
1.50	686.25	35.1242
1.50	686.73	56.2988

Table D-2: AS4/3501-6 $[90]_{20}$ graphite/epoxy damping data
Horizontal Orientation

SPECIMEN BEAM LENGTH (in.)	FIRST RESONANT FREQUENCY (Hz)	DAMPING LOSS FACTOR ($\times 10^{-4}$)
10.34	14.90	109.774
10.34	14.93	99.835
10.34	14.93	100.711
10.34	14.94	101.748
10.34	14.95	108.674
8.00	25.00	97.630
8.00	25.00	109.152
8.00	25.01	104.044
8.00	25.03	116.272
8.00	25.05	107.351
8.00	25.06	117.887
6.00	44.20	85.394
6.00	44.77	92.542
6.00	44.85	93.533
6.00	44.87	94.634
6.00	47.10	84.442
6.00	47.11	86.121
6.00	47.12	88.135
6.00	47.16	82.131
4.00	100.02	62.552
4.00	100.07	61.651
4.00	100.09	59.631
4.00	100.22	59.760
3.75	101.40	61.775
3.75	101.44	50.502
3.75	101.51	55.716
3.75	101.59	52.221
3.75	102.40	54.091
3.00	179.96	44.476
3.00	181.50	45.259
3.00	181.96	42.995
3.00	182.27	40.654
2.38	266.64	38.301
2.38	266.74	34.811
2.38	266.87	39.288
2.38	266.90	35.157
2.38	266.92	36.070
1.88	422.35	34.659
1.88	422.54	31.644
1.88	422.75	32.743
1.88	423.15	32.189

Table E1: AS4/3501-6 ± 45 Degree Graphite/Epoxy Loss Factor Data
Vertical Orientation

SPECIMEN BEAM LENGTH (in.)	FIRST RESONANT FREQUENCY (Hz)	DAMPING LOSS FACTOR ($\times 10^{-4}$)
10.0(16ply)	18.03	27.2400
10.0(16ply)	18.03	27.3811
10.0(16ply)	18.03	27.5638
10.0(16ply)	18.04	27.2135
10.0(16ply)	18.04	29.5209
7.25(8ply)	18.65	27.0645
7.25(8ply)	18.65	30.5579
7.25(8ply)	18.65	25.2708
7.25(8ply)	18.65	30.0042
7.25(8ply)	18.66	26.3490
8.0(16ply)	28.05	28.4654
8.0(16ply)	28.05	31.0770
8.0(16ply)	28.06	31.1507
8.0(16ply)	28.08	31.1161
8.0(16ply)	28.09	30.2010
5.875(8ply)	28.45	35.8492
5.875(8ply)	28.45	33.3239
5.875(8ply)	28.45	30.2732
5.875(8ply)	28.45	34.2046
5.875(8ply)	28.47	37.2737
6.0(16ply)	42.93	35.7599
6.0(16ply)	42.95	41.3122
6.0(16ply)	42.96	39.6989
6.0(16ply)	42.98	43.9739
6.0(16ply)	42.99	39.6394
4.75(8ply)	44.42	38.2323
4.75(8ply)	44.46	35.4545
4.75(8ply)	44.48	36.6628
4.75(8ply)	44.49	36.9270
4.75(8ply)	44.51	42.2387
6.0(16ply)	50.78	29.6857
6.0(16ply)	50.81	33.5284
6.0(16ply)	50.81	34.0490
6.0(16ply)	50.83	34.6442
6.0(16ply)	50.83	37.3004
6.0(16ply)	50.86	39.1617
4.375(8ply)	52.69	32.7695
4.375(8ply)	52.70	35.2453
4.375(8ply)	52.72	36.5482
4.375(8ply)	52.72	35.1056
4.375(8ply)	52.74	37.7846

Table E1: AS4/3501-6 $\pm$45 Degree Graphite/Epoxy Loss Factor Data
Vertical Orientation

SPECIMEN BEAM LENGTH (in.)	FIRST RESONANT FREQUENCY (Hz)	DAMPING LOSS FACTOR ($x\ 10^{-4}$)
5.0(16ply)	73.79	27.4912
5.0(16ply)	73.80	29.3428
5.0(16ply)	73.81	28.4894
5.0(16ply)	73.82	30.6481
5.0(16ply)	73.82	30.3739
3.625(8ply)	75.21	34.0268
3.625(8ply)	75.41	35.1948
3.625(8ply)	75.42	32.6057
3.625(8ply)	75.42	32.4871
3.625(8ply)	75.45	37.1243
4.0(16ply)	117.38	27.3637
4.0(16ply)	117.38	29.1788
4.0(16ply)	117.40	26.9988
4.0(16ply)	117.41	28.3472
4.0(16ply)	117.44	25.3034
3.0(8ply)	110.49	29.5692
3.0(8ply)	110.52	28.2822
3.0(8ply)	110.56	27.8018
3.0(8ply)	110.57	29.3252
3.0(8ply)	110.60	27.3743
3.0(16ply)	214.23	32.5414
3.0(16ply)	214.27	31.9237
3.0(16ply)	214.32	31.9635
3.0(16ply)	214.33	31.0624
3.0(16ply)	214.37	29.5051
2.2(8ply)	213.92	32.7140
2.2(8ply)	214.00	38.6667
2.2(8ply)	214.16	32.0959
2.2(8ply)	214.18	30.7630
2.2(8ply)	214.40	28.7779
2.2(8ply)	214.59	31.1434
2.2(8ply)	214.84	39.1169
2.5(16ply)	316.62	24.7449
2.5(16ply)	316.70	24.2718
2.5(16ply)	316.72	30.0821
2.5(16ply)	316.73	25.3075
2.5(16ply)	316.76	24.8687
2.5(16ply)	316.79	30.1734
1.8125(8ply)	306.38	41.6973
1.8125(8ply)	307.40	41.4540
1.8125(8ply)	307.49	36.9666
1.8125(8ply)	307.61	36.7673
1.8125(8ply)	307.91	38.3641
1.8125(8ply)	308.78	36.7896

Table E1: AS4/3501-6 $\pm$45 Degree Graphite/Epoxy Loss Factor Data
Vertical Orientation

SPECIMEN BEAM LENGTH (in.)	FIRST RESONANT FREQUENCY (Hz)	DAMPING LOSS FACTOR ($\times 10^{-4}$)
3.0(32ply)	409.91	43.7538
3.0(32ply)	410.63	45.6211
3.0(32ply)	410.96	38.3839
3.0(32ply)	411.02	44.3264
3.0(32ply)	411.18	43.7827
3.0(32ply)	411.41	36.5903
2.125(16ply)	440.71	31.0484
2.125(16ply)	440.78	37.3575
2.125(16ply)	440.90	29.1990
2.125(16ply)	440.95	31.1540
2.125(16ply)	441.07	26.7328
2.125(16ply)	441.16	34.4980
2.125(16ply)	441.46	37.4634
2.125(16ply)	441.93	27.2899

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